NOTES ON RADIUM-BEARING MINERALS

WYATT MALCOLM

Prospector's Handbook
No. 1

CANADA
DEPARTMENT OF MINES
HON. LOUIS CODERRE, MINISTER; R. W. BROCK, DEPUTY MINISTER.

GEOLOGICAL SURVEY

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Introduction

Much interest has been aroused in recent years over the discovery of the element radium. It is found associated with uranium, but in practically infinitesimal quantities, only a few grains per ton. It is separated from the ore as a chemical compound and placed upon the market as such. The difficulty of recovering the radium from the ore and the superior technical skill required in the operation make the cost of separation extremely high, and necessitate the fabulous prices paid. It is much in demand by scientific institutes, institutions for investigations in radium-therapy, hospitals, and practising physicians.

As an aid to the prospector the following notes on the occurrence of uranium ores, from which the supply of radium is obtained, have been compiled. These are followed by a list of occurrences in Canada and suggestions as to localities that might be prospected.

Uranium Minerals

A great variety of uranium minerals have been recognized, but the most of them are of rare occurrence. Those that occur chiefly in commercial quantities are pitchblende or uraninite, carnotite, and autunite.

Pitchblende carries a much higher percentage of uranium than either of the other two, and is a uranate of uranyl, lead, usually thorium (or zirconium) and, often, the metals of the lanthanum and yttrium groups; it also contains nitrogen in varying amounts up to 2·6 per cent. It is brittle, has a conchoidal or shell-like fracture, is of a submetallic to greasy, pitch-like or dull lustre, is opaque, and in colour is greyish, greenish, brownish, and velvet black. Its hardness is 5·5; that is, it is nearly as hard as feldspar. The specific gravity of crystals, which are rare, is 9 to 9·7. In the massive state its specific gravity is 6·4; that is, it is between two and three times as heavy as a piece of quartz, limestone, or granite of equal size. The greasy or pitch-like lustre and the high specific gravity are striking features of this mineral.

Carnotite is a mineral varying somewhat in composition and containing vanadium and uranium, with either or both lime and potash. It is a canary-yellow, and powdery or waxy-looking mineral. "With a hand lens it can in places be seen to have a somewhat radial but rather indefinite crystal form. Very rarely it takes a solid form, which cuts like paraffin and has an unctuous feel. In the powdery form the colour may be somewhat disguised by iron oxide or calcium vanadate." [1]

Autunite is a phosphate of uranium and calcium. It is translucent, bright yellow in colour, and occurs in small plates or tabular crystals or in micaceous aggregates.

Chalcolite or torbernite is a hydrous phosphate of uranium and copper. It occurs in square tabular crystals, thin or thick; it is found also in foliated and micaceous aggregates. It has a pearly to subadamantine lustre, and is transparent to translucent. It is emerald green and grass green, some specimens being apple or siskin green. Hardness 2 to 2·5; specific gravity, 3·4 to 3·6.

[1]Hess, Frank L.: Uranium and Vanadium. U. S. Geol. Survey, Mineral Resources, Pt. 1, Metals 1912, pp. 1003-1037.

TESTS

An electroscope is useful in making tests for radium, but it cannot always be carried about conveniently. The scintilloscope is a much more convenient instrument. It should, however, be carefully tested with a mineral known to be radioactive before taking it to the field; its usefulness may be lost by careless handling.

An electroscope is a metal box, through an opening in the top of which a metal strip is suspended by means of a bit of sulphur or amber so that it is insulated from the box. Resting against the metal strip and attached to it by its upper end is a strip of gold leaf. When the metal strip and gold leaf are charged with electricity the latter diverges from the former at an angle. The divergence can be viewed through an opening in the side of the box. The electroscope discharges slowly under ordinary conditions and the gold leaf returns to its original position. The rate of discharge is hastened by bringing a radium-bearing mineral near the instrument. It is a delicate instrument and requires some skill in manipulation.

The scintilloscope consists of a closed brass cylinder, provided at one end with a lens and coated interiorly with zinc sulphide. A radium-bearing mineral brought close to this instrument produces scintillations in the zinc sulphide that can be viewed through the lens in a dark room. This instrument can be had for a dollar or two from Gallenkamp & Co., 19-21 Sun Street, Finsbury Square, London, E.C., England.

If uranium is present in quantities likely to be commercial it can be detected by the radioactivity of its decomposition products by laying the suspected specimen upon a plate holder containing a sensitive photographic plate and leaving it from twelve hours to one week. If uranium is present in any considerable quantity the plate will be light-struck. It is well to note, however, that minerals containing thorium produce the same effect upon a photographic plate.

The presence of carnotite is indicated by a yellow colour brought out in a specimen when it is heated, as by laying it on the top of a stove.

All the above tests require more or less skill and experience in their application and it is always advisable for the inexperienced person to submit a suspected specimen to an expert for examination.

Some of the Most Important Occurrences of Uranium Minerals

The following descriptions of uranium deposits are given for the purpose of showing the mode of occurrence of radium-bearing ores in commercial quantities.

Portugal.

Important deposits of uranium ore in pegmatite dykes are found in northern Portugal.[1] They have been described by Segaud and Humery. The following notes may be of interest.

The deposits are situated in a granite massif and to a less extent in adjacent Cambrian schists. The uranium minerals are closely associated with tin and tungsten deposits; within the same region occur veins of galena, of mispickel, and of galena and chalcopyrite. The uranium minerals occur in pegmatite dykes, which vary much in thickness, disappearing sometimes completely to reappear a few yards farther on. A thickness of 20 to 40 inches is common. Similar variations occur on the dip as on the strike. The pegmatite consists of very coarsely crystallized quartz and feldspar; in some places feldspar predominates,

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[1]Deposits of uranium in Portugal: Ann. des Mines, ser. 11, vol. 3, February, 1913, pp. 111-118.

and in others it gives way to quartz. The gouge is argillaceous and may carry uranium; when argillaceous material is found throughout the dyke it may be strongly uranium-bearing. The chief minerals are autunite, a uranium-calcium phosphate, and chalcolite, a uranium-copper phosphate. The former occurs as small plates and particles of a bright yellow colour. When disseminated through the argillaceous matter it is sometimes completely invisible and can be detected only by means of the electroscope. The chalcolite is of a beautiful emerald green colour. The mineral content of the dykes varies much both horizontally and vertically. Autunite and chalcolite are found above the water level; presumably an unaltered mineral of a different nature will be found at greater depth. These deposits are being mined and the ores chemically treated.

Gilpin County, Colorado.

The following description of the pitchblende deposits of Quartz hill, Gilpin county, Colorado, is taken from a paper by Forbes Rickard appearing in the Mining and Scientific Press of June 7, 1913:—

"Near the west end of Quartz hill are several mines which have been known to produce pitchblende, usually in small quantity but of high quality in respect to uranium content. Measured by present day standards, these ores are known to be more radio-active than any others that have been found, notwithstanding that the search has been world-wide.......................

"The Kirk, German and Wood mines, all on Quartz hill, are among the more important and best known.......

"This district is one in which gneiss and crystalline schist predominate, with numerous intrusive andesitic dykes of varying composition and texture; acid granitic dykes are less numerous, but their occurrence is important in this connection, for, in association with the veins of these mines there occurs, in intrusive form, a fine-grained aplitic granite, which is closely associated with the pitchblende. This granite takes dyke form, occasionally putting out tongues and more rarely taking the shape of connecting sills. . . . .

"Respecting the correlation of the rocks of this formation, Archæan gneisses and crystalline schists are intruded by granitic dykes, and long subsequent to this belong the porphyry intrusions of the andesitic rocks. These later dykes are of the andesitic type—andesites, quartz-andesites, and dacites. In thin plates, examined under the microscope they show a micro-crystalline groundmass, with porphyritic feldspar, phenocrysts, and much altered pyroxene. Nowhere in the mines, so far as mine workings have gone, do dykes of these two systems intersect.

"The veins themselves, without exception, have a well defined northeast-southwest trend. Similarly, without exception, the fine grained granite intrusive is common to all veins sharing in the pitchblende distribution. It is significant that some intervening veins, yielding profitably gold-silver ores but not pitchblende, are bounded by walls of crystalline metamorphic schist, the granite intrusive being absent. This plainly suggests the derivation of the older fine grained granite from a main mass, which, in its intrusion into the fissures in the state of magma, favored some and not others of these veins.

"Ore deposits of this district furnish two types of ore: one being characterized by pitchblende, with accessory pyrite in varying quantity, with sphalerite and galena in subordinate quantities, and sometimes marcasite and stibnite, but in much less degree; the other type of ore includes the minerals pyrite, chalcopyrite, sphalerite, and galena, with varying gold and silver content. Quartz is plentiful in the gangue. It is also often found lining vugs or cavities in the vein.

"It is axiomatic in these mines that as pitchblende comes in the gold goes out.....................

"The underground workings of the German and Belcher mines are connected at the first and second levels. As they are under the same ownership they are worked as one mine. The pitchblende vein, as previously noted, is accompanied by a granite dyke more or less shattered, and at times occupies a position which is central in respect to the dyke itself. The dyke varies in width from 5 to 9 feet. The vein varies from 4 or 5 in. to 18 or 20 in.; it is generally marked by a narrow gouge or selvage on its hanging wall side. Veinlets extend from the vein proper into the fracture seams in the granite.

"The more solid pitchblende, either in lens form or in well-defined streak, seldom exceeds three to four inches in width. Where the vein reaches its maximum width the proportion of uraninite is inversely small, though for the whole width (apart from the high-grade bunches) the vein carries sufficient pitchblende to constitute a grade of ore for concentration from 2½ to 4% U_3O_8.............

"Outside of the general policy of development adopted by the management a small amount of pitchblende ore is being mined. By crude hand-sorting within the shaft house, there is now being produced in small but increasing quantity, a selected grade of pitchblende carrying 15 to 60% uranium oxide (U_3O_8). An average of approximately 30% U_3O_8 is established and can probably be maintained in quantity of several tons per annum. The bulk of ore suitable for mill treatment accumulates in the proportion of something like 40 tons to 1 ton of 'selected pitchblende.'

"These mines of Quartz hill, though they may be small mines, have advantages over larger mines in other districts, in that: (1) there is no extensive faulting or dislocation of the veins; (2) no great investment is needed for a mill, or for railroad transportation; and (3) there is no extra pumping expense. While in the German mine the partly massive pitchblende is streaked by pyrite, in the Belcher mine the reverse is true. These streaks run through the vein for practically the whole length of a stope, say 100 ft. long, and at intervals, enlarge into pockets of high-grade ore. The point of such enrichment corresponds with the swells in the vein itself. In both mines the gangue of the pitchblende vein is of pegmatic (pegmatitic) character; it is locally termed spar. Vein-quartz, which is plentiful in the gold-silver vein, is not seen in association with pitchblende ores.

"The gold-silver vein belongs to a post-mineral fracturing; that is to say, long subsequent to the building up of the pitchblende vein in association with the granite (aplitic), there was a fault movement along the plane of the vein along lines approximating the northeast-southwest course of the already existing vein. Lines of least resistance would naturally govern in the creation of new channels for the later vein-forming agencies, and these have in the main followed the north or foot-wall side of the granite intrusive. While the gold-silver vein, in the main, occupies the foot-wall side of the mine, at a point between the German and Belcher shafts, it crosses the pitchblende vein and diverges from it as it goes eastward. The gold-silver vein continues strong and productive beyond the intersection. The granite accompanying the pitchblende has a way of feathering out at times into the mica-schist rock; and while nothing like dislocation or faulting of the granite has yet been observed, this may exist and will probably be found as mine work is extended. . . . .

"It is remarkable that little or no placer pitchblende has been found in the vicinity, though in Nevada gulch, immediately to the north, much placer work was done in the early days of mining, and much surface work in pits and trenches has been done in connection with assessment work of later times."

Cornwall, England.

Speaking of the tin deposits of Cornwall[1] Beck says: "In this region the slates, which are mostly of Devonian age, are traversed by five large and several small stocks of tourmaline-bearing granite. Both the slates, locally called *killas*, and the granite are cut by numerous dykes, some as much as 120 m. (393 ft.) thick, of quartz porphyry, also tourmaline-bearing, called *elvans*. These dykes also traverse Carboniferous rocks (Culm). The granite intrusions, whose contact generally dips gently below the slates, have caused considerable contact metamorphism, transforming the slates into green, purple and violet hornfels and similar rocks. All these rocks are traversed by lodes of copper and tin ores, which have a great tendency to break up into stringers and often pass into an exceedingly fine network of veins. These are especially numerous near the granite masses. Their strike is mostly between east and east-northeast; their dip is ordinarily 20 to 50° north. The thickness may rise to 1·5 meters, but it is mostly much less. The principal gangue is quartz, with associated orthoclase, tourmaline, chlorite, lithia-mica and some fluorspar. The tin veins contain cassiterite, stannite, copper pyrite, tungsten, blende, arsenopyrite, native bismuth and other rarer minerals; the copper lodes proper also contain gray copper, tennantite, cuprite, native copper, malachite, azurite, pyrite, arsenopyrite and blende. A remarkable feature is the change in the nature of the ore in many lodes

[1]The Nature of Ore Deposits, translated by W. H. Weed, p. 211.

when they pass from the slate into the granite, the pure copper becoming tin deposits........................ Some lodes are filled by a breccia enclosing many fragments of the country rock; but the vein filling is generally massive, in some cases showing a symmetric banded structure. The veins are accompanied by zones of impregnation, some of them very wide, which are also worked for tin, and have furnished the main bulk of the ores turned into the furnace.

"While the vein fissure itself is often only a few centimeters thick, the 'lode' as worked is several meters in thickness, and is formed of granite altered to greisen. The so-called Carbonas of St. Ives is worked for tin ore, to which its high content of tourmaline imparts a dark colour. This greisen rock forms very irregular deposits connected by a transverse fissure with one of the main lodes of that locality. These deposits consist mainly of feldspar, quartz, tourmaline and cassiterite, associated sometimes with fluorspar, lithia-mica, copper pyrite and iron pyrite. In the slate also the altered rock of the zones of impregnation is rich in cassiterite and is mined, being called *capel*. This dark-coloured rock consists mainly of quartz and tourmaline, with short quartz stringers interpolated, and is traversed by small stringers of tinstone and chlorite. These *capels* accompany the cassiterite veins ('leaders')."

Uranium-bearing minerals are found in a number of the Cornwall mines. Ussher, Barrow and MacAllister, in their description of the geology of the country around Bodmin and St. Austell, give the following description of the uranium-bearing veins:—[1]

"Throughout the region, with the exception of the district in the eastern part of the map, there occur here and

[1]Geology of the country around Bodmin and St. Austell; Mem. Geol. Sur. of England and Wales, 1909, p. 134.

there lodes younger than those of tin or copper. These lodes are probably of different ages, but their association with the mineral district as a whole makes it probable that they are genetically connected with the eruptive after-actions following the intrusion of the granite and elvans. Some of these lodes contain minerals which also characterize tin lodes, such as arsenic and copper, and in small quantities uranium, cobalt, and nickel ores. The younger lodes have been formed in fissures crossing the tin and copper lodes and in bearing they vary from due north and south to a northwesterly direction, similar to the cross courses."

"Of the younger lodes there are two well-marked series, those containing uranium and nickel ores, and those which have yielded considerable quantities of iron ore and some manganese. In addition to these, argentiferous galena also occurs sometimes with zinc and iron pyrites in lodes, the bearing of which is varied, but is frequently either north and south or in directions similar to those of the tin and copper lodes."

The most important producer of uranium ore in Cornwall is the South Terras mine, now known as the Uranium mine. It is situated in the valley of the Fal. "The country rock is killas[1] with intrusive greenstone which has been quarried for road metal. The sett[2] is traversed by three elvans[3]. The mine attracted some attention lately on account of the general scarcity of uranium for scientific purposes. The uranium lode has a bearing north and south and an underlie to the west of about 10 degrees. It is said to vary in width from 3 to 5 feet, but the uranium ore is confined to a leader a few inches in width, consisting partly of pitchblende and calc- and copper-uranites, with copper pyrites, mispickel and galena, and small quantities of

[1]Slate.

[2]Quartz porphyry.

[3]Mining property (?)

nickel, cobalt, and chromium ore in a veinstone of quartz and green garnet rock. Assays by Messrs. Johnson, Matthey & Co., show that the so-called 'green ore' contained 6·2% of uranium oxide, while the 'dark ore' contained 36% of the same."

According to J. H. Collins[1] "the ore occurs in beautiful light-green, yellow, and brown flakes, scales, and crystals ....the ore is altogether light and friable, and much of it is lost in the process of hand picking. Some specks of the hard and heavy pitchblende have, however, been seen, and as the works are carried down below the water level it may fairly be expected that a large proportion of pitchblende will be found. A level has been driven in this lode for a distance of 150 fathoms, and in all, counting several small stopes above the adit, about 400 fathoms of lode have been taken away, working with only four men. This, according to statements made to me by the representatives of the owners, has yielded about 50 tons of hand-picked ore, of which 10 tons have been consigned to the selling agents since June 1, and a further quantity of 5 or 6 tons is still on the ground............................ The ore sold has realized an average value of £40 per ton, the first quality running as high as £280 and the lowest £22. Perhaps an equal quantity has for a time been lost in the refuse, most of which could be recovered by a proper system of local chemical treatment at a good profit.[2]

"I need not enter into the vicissitudes of this mine, worked as it was by different companies and under different names during the next 18 years. In September, 1907, having been again called upon to inspect, I reported upon the

[1]Observations on the west of England mining regions. Plymouth, 1912.

[2]Extracts from a report made by J. H. Collins and dated Aug. 2, 1889.

uranium lode as follows: 'The uranium lode is 2 to 4 feet wide, and there is a more or less continuous leader of valuable ore, varying from a mere knife-edge up to a foot or more in thickness. The workings have now reached a depth of 30 fathoms below the adit level, and only pitchblende is now found in the lode, so that it is easy by hand selection to separate the high-grade ore, while the remainder can readily be dressed in the ordinary way (by crushing and wet concentration). The 30-fathom level has now been driven for a total length of nearly 80 fathoms, and the ground thus opened up between this and the 20-fathom level is certainly not likely to yield less ore for equal length than that already yielded between the 20 and the 10, or between the 10 and the adit.'

"As illustrating the value of the ore ground, it would appear that up to the present about 1000 fathoms of ore ground have been stoped away above the 20-fathom level and 500 tons of ore sold for approximately £20,000, while there is probably at least £5,000 more recoverable from the dumps."

Joachimsthal, Bohemia.

"[1]The Joachimsthal district lies on the higher southern slope of Erzgebirge, southwest of its highest elevation, the Keilberg, 1238 m. high, near the Saxon boundary. The rocks are mica schists, with east-west to west-northwest foliation and north dip. In the vein area finely crystalline, slaty mica schists predominate, with intercalated layers of calcareous mica schists, crystalline limestones and coarse-fibred mica schists. Toward the northeast and east gneisses occur, while toward the southwest the schist ends abruptly against

[1]Beck, Richard: The Nature of Ore Deposits, translated by W. H. Weed, 1905, pp. 283.

granite, the northeast contact of the great Eibenstock-Karlsbad massive of tourmaline granite, which crosses the axis of the Erzgebirge. At its border a contact zone is developed, which, however, does not quite extend into the Joachimsthal mineral vein area. Numerous dykes of quartz porphyry, sometimes quite large and running northwest to north-northwest, traverse both the region northeast of the granite, and the mineral area. Dykes of basalt and phonolite, as well as bosses of these rocks, were intruded in Tertiary time........................

"According to their strike, the silver-cobalt veins of Joachimsthal, especially those close to the town on the northwest, fall into these two groups.

"(a) Morgengänge, striking east-northeast (7 hours) and dipping north at 60-80°; (b) Mitternachtgänge striking north-northeast to north-northwest, for the most part, almost exactly north-south (11-1 hours) and dipping at times 45-85° west or east..................

"The width of the veins varies between 15 and 60 cm. and only exceptionally reaches 1-2 m. (3·28 to 6·56 ft.). Stringers are common. Some of the Mitternacht veins reach the surface not as true veins, but as narrow, barren cracks.

"The filling is not the same in all the veins. Thus in the western Mitternachtgänge it is for the most part a brittle clay, with quartz and hornstone; in the eastern veins it is mostly calcspar and dolomite, while both sets of veins occasionally show a brecciated structure. The ores in these gangues form stringers, branches and pockets that are very spotty. According to G. Laube, these ores may be divided into:

1. Silver ores (native silver, argentite, polybasite, stephanite, tetrahedrite, proustite, pyrargyrite, sternbergite, argentopyrite, besides rittingerite, acanthite and cerargyrite).

2. Nickel ores (niccolite, chloanthite, millerite).
3. Cobalt ores (smaltite, as well as bismuth-cobalt-pyrite and asbolate).
4. Bismuth ores (native bismuth, as well as bismuth glance and bismuth ocher).
5. Arsenic ores (native arsenic, arsenopyrite).
6. Uranium ores (pitchblende).

"Galena, zinc-blende, pyrite, marcasite, copper pyrite and bornite only occur subordinately and occasionally. Among these ores, the cobalt and nickel ores appear to be on the whole the older, the silver ores the younger.........

"Near the lode fissures, the country rock frequently has been impregnated with extremely finely divided ore particles. This explains the small percentage of metals shown by F. Sandberger and A. Seifert to exist in various rocks of Joachimsthal, especially copper, cobalt, nickel and arsenic. In like manner the presence of minute granules of uranium pitchblende in a scapolite-mica-schist of that locality, first discovered by F. Sandberger and conclusively confirmed by F. Babenek and A. Seifert, by means of large-scale ore concentration experiments, is most naturally explained by an infiltration from the lode fissures. Their presence as primary constituents seems to be gainsaid by their very unequal distribution in the rock. ....

"The veins traverse dykes of quartz porphyry, and in their turn are cut across by dykes of basalt and the *wacke* veins. However, since these *wackes* sometimes contain some interspersed argentite (earthy silver glance) where they cross the ore veins, it is inferred that at the time of the eruption of the younger vulcanic rocks the vein formation had not yet been quite completed...........

"At the acute-angled lode crossings there has been an enrichment of the ore. The veins are richer in the porphyry and to the east in the limestone intercalation than in the schist."

It was formerly thought[1] that the pitchblende was limited to the north-south veins but more recent mining operations have revealed its presence, although in smaller quantities, in the east-west veins. There is very commonly an enrichment at the intersection of veins of the two different sets.

The pitchblende is not evenly distributed throughout the veins, but occurs in fragments and lenses in intimate association with dolomite and calcite. The carbonates in the vicinity of the pitchblende take on a red to reddish brown colour, which serves as an indicator of the isolated bodies of ore.

Carnotite in Colorado and Utah.

Carnotite is one of the most important uranium minerals produced by the United States. It occurs chiefly as impregnations in sandstone beds, and filling cracks and other cavities in the sandstone and in fossils embedded therein. It is mined in Colorado and Utah. The following quotations from "A Preliminary Report on Uranium, Radium, and Vanadium," by Richard B. Moore and Karl L. Kithil[2] will serve as a description of the mode of occurrence of the ore.

Coal Creek, Colorado. "The next pit, No. 3, just below No. 2, and southwest of it on the same hill, contains a petrified tree about 12 inches in diameter lying halfway across the pit. Cracks and interstices in this tree, which is a rusty brown, are filled wifh powdery yellow carnotite. The sandstone for 1 foot below the tree carries good ore. Under the grass roots the sandstone is soft and rather heavily impregnated with carnotite. Farther below in the

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[1]Krusch, P.: Radiumlagestätten und Radiummarkt, Zeitschrift für praktische Geologie, 1911, p. 86.

[2]Bureau of Mines, Wash., Bulletin 70, 1913.

white sandstone, a brownish-yellow streak occurs, underlying which is a somewhat richer yellow material a few inches in thickness. On the right side of the pit, near the bottom, is a brownish-coloured rock containing vanadium."

Green River, Utah. "The majority of the deposits are exposed in the gulleys that traverse the 'reefs.' The carnotite is always in a rather coarse sandstone overlain with fine conglomerate. Much petrified wood is exposed, also bones and other fossils. As at Meeker, the carnotite stains are conspicuous about the wood, much of which is heavily impregnated. The yellow ore is found mostly in or near the wood or in cracks in the sandstone, although both the sandstone and the darker ores are lightly impregnated in many places. Yellow ore such as occurs in Paradox Valley is largely absent here, most of the ores being dark coloured. They may be divided into four general types—the yellow carnotite, found mainly in cracks; a dark-brown siliceous ore impregnated with carnotite; a black ore, much of which is associated with carbonaceous material and some of which carries stains of carnotite; and a grayish-brown laminated sandy shale, rich in vanadium and carrying some uranium. Parts of the deposits show mixed ores, but the majority of them can be classified as above."

"Many samples that show little or no carnotite, turn yellow on exposure to the air for several weeks. This yellowing takes place quickly if the ore is heated, as by laying it on the top of a stove. Such a test frequently shows uranium in ores not suspected of containing it, and as the test is well adapted to fieldwork, it merits a wider use. . . . .

"During the year 1912, 346 tons of ore was shipped from Green River, Thompsons, and Cisco, the only points in Utah that shipped ore. A part of this carried less than 1 per cent U_3O_8 and the returns did not equal expenses. It is doubtful whether any of the ore carried 2 per cent U_3O_8: most of it carried about 1·5 per cent. Approximately 125 tons additional was mined and stored but not shipped." . . . .

Paradox Valley, Colo. "The ores of the Paradox district differ in many respects from those of Utah, chiefly in carrying larger proportions of carnotite, and, as a rule, are more yellow. . . . .

"The most typical ore is a sandstone so impregnated with yellow carnotite that the colour is decidedly noticeable and containing small kidneys of brown sandy clay. The kidneys constitute a considerable part of some of the ore; in many cases they are thinly scattered through the sandstone. It seems to be generally accepted among the operators that the kidneys are rich in vanadium. The samples we have tested show vanadium. Although ore of the character mentioned is widely distributed in the Paradox and adjacent districts and constitutes a large part of the ore shipped, it is by no means the only ore of commercial importance. Indeed the variety of the types of ore here and also in Utah is one of the interesting features of the uranium and vanadium deposits. We have had time to test only a few of the large number of samples taken. There are dark-blue, brown, and black vanadium ores, the dark-blue ores being lustrous when first mined and usually carrying uranium; high-grade carnotite in 'bug holes' so soft that it can be molded in the fingers; the same kind of ore crystallized with gypsum; and red calcium vanadate, some in radiated form, and some mixed with carnotite and blue vanadium ore. Much of the very low-grade ore on exposure to the air weathers to green, rose, or yellow colour, or to all three colours intermingled. In many places several ores of different types are mixed in intricate mass; in other places the sandstone is impregnated along the lines of stratification and there are alternate layers of carnotite and dark vanadium ore.

"The deposits are invariably pockets, many of which, however, are of considerable size; 50 tons of shipping ore from a single claim is not unusual. Several claims have yielded more than this."....................

"It is difficult to form a definite opinion as to the origin of the carnotite and vanadium deposits. Hillebrand and Ransome show that the ores must have been carried to their present position and that the vanadium and uranium compounds could not have been the original cementing material of the quartz grains, but in all probability locally replaced the calcite that forms the matrix of the light-coloured sandstones in which the ores occur. They express the opinion that the carnotite resulted from local concentration of material already in the sandstone, and that its deposition as carnotite was under conditions determined by proximity to the surface and probably was partly dependent on a semiarid climate...................

"The so-called 'bug holes' appear to have escaped the notice of Hillebrand and Ransome. Many of these holes are 30 to 40 feet long and 2 to 5 inches in diameter; the walls are usually incrusted with quartz or gypsum. Almost invariably these holes run downward at a slight angle into the upper parts of an ore body, although a few enter the lower part of a deposit, and end abruptly in the ore. They are filled with high-grade ore, usually carnotite, although in some the blue and black ores of vanadium predominate. The other end of these 'bug holes' opens into a funnel-shaped mass of soft sandstone, heavily impregnated with ore, that grades into the country rock. The appearance of one of these 'veins' is that of a funnel with a long stem. Undoubtedly these holes represent channels through which ore-bearing solutions were transported. How far the ore-bearing solution travelled and whence it came are questions more difficult to answer."

Canadian Occurrences.

Radium-bearing minerals have not been found in economic quantities in Canada. There are a few localities, however, in which such minerals have been discovered in traces or small quantities.

Madoc, Ontario. Uraconite has been mentioned as occurring in the form of a sulphur-yellow crystalline crust lining fissures in the magnetite of the Seymour ore-bed, lot 11, concession V of Madoc, Hastings county, Ontario.

Mamainse, Ontario. Many years ago uraninite was reported as forming a vein about 2 inches wide at the junction of the trap and syenite at Mamainse on the east shore of Lake Superior. [1]"It was first described in 1847 by Dr. J. L. Leconte as a new ore of uranium, under the name coracite. It is amorphous, pitch-black in colour, with a grey streak, a resinous lustre and a conchoidal fracture. Its hardness is 3·0, and its density 4·38................. contains oxyd of uranium 59·30, lime 14·44, oxyd of lead 5·36, oxyd of iron 2·24, alumina 0·90, silica 4·35, carbonic acid 7·47, water 4·64 with traces of magnesia and manganese = 98·70." Search has been made for this vein in recent years, but without success.

Maisonneuve, Quebec. Samarskite occurs somewhat abundantly in excavations made in a pegmatite dyke on Mica lake, lots 1 and 2, range II of Maisonneuve, Berthier county, Quebec. A sample described by Hoffmann[2] had a sub-metallic, shining lustre, was opaque, and of a brownish-black colour. It was brittle, had a greyish-brown streak, hardness 6, and specific gravity 4·9. It contained 10·75 per cent of uranium oxide.

Murray Bay, Quebec. A variety of uraninite or pitchblende has been found in a mica mine near Lake Pieds

[1]Geology of Canada, 1863, p. 504.
[2]Geol. Sur. Can., 1880-81-82, p. 1 H.

des Monts; about 18 miles back of Murray Bay in the county of Charlevoix, Quebec. At the same locality a carbonaceous mineral, carrying 40·185 per cent volatile matter (including volatile combustible matter and a small quantity of moisture), 52·590 per cent fixed carbon and 7·225 per cent ash, was found, and the ash carried 35·43 per cent uranium.[1]

Snowdon, Ontario. Uraconite has been reported as occurring with magnetite on lot 20, concession I of Snowdon, Peterborough county, Ontario.

Villeneuve, Quebec. Pitchblende was discovered at the Villeneuve mica mine on lot 30, range I, of Villeneuve, Ottawa county, Quebec.[2] "The vein in which the mica occurs has been described as a coarse pegmatite, cutting a greyish garnetiferous gneiss. It is composed of quartz, muscovite, microcline and albite, with occasionally black tourmaline and garnet. The specimen (pitchblende), to which was attached a little muscovite, weighed about one pound and consisted apparently of the greater portion of what had been a lenticular nodule. Structure, massive. Specific gravity (15·5°C.), as determined by Mr. Kenrick, 9·055. It had on one portion of its surface a moderately thick incrustation, the prevailing colour of which was yellowish-red to scarlet-red. A small portion of the same had, however, a pure sulphur yellow colour. This material, which is most probably gummite, was found by Mr. Kenrick to have a specific gravity (15·5°C.) of 3·78." A sample of pitchblende from this mine was found to carry 37·70 per cent of uranium oxide.

Wakefield, Quebec. Small quantities of uraninite and gummite have been reported from the Leduc mica mine, lot 25, range VII of Wakefield, Ottawa county, Quebec. The mine is in a pegmatite dyke.

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[1] Obalski, J.: On a mineral containing radium in the Province of Quebec. Can. Min. Inst. Jour., vol. 7, p. 247.

[2] Hoffmann, G. C.: Geol. Sur. Can., vol. 2, p. 10 T.

Conclusions

An examination of the descriptions of the occurrences of uranium or radium-containing ores shows that they are nearly all associated with igneous rocks of an acid character such as granites, pegmatite dykes, and quartz porphyry dykes. They are found enclosed within the body of pegmatite dykes or in veins cutting granite, or schists or slates intruded by granite or porphyry dykes, and probably have their origin in solutions given off by these igneous rocks at or about the time of intrusion.

These minerals have a great variety of mineral associations. In Colorado they are associated with pyrite and small quantities of galena and zinc blende, in Joachimsthal with silver, cobalt, and nickel ores, in Portugal with tin and tungsten minerals, and in Cornwall they are found in the tin and copper mining district.

The carnotite deposits of Utah and Colorado constitute an exception to the usual mode of occurrence. Here the uranium-vanadium mineral carnotite occurs with other vanadium minerals as an impregnation in sandstone beds and in cavities and cracks in the sandstone and in fossils.

The great variety of mineral associations of uranium makes it advisable that the prospector should not neglect a careful search for its presence in all known mineral deposits, especially those that are genetically related to intrusions of granite and closely allied rocks. Localities where traces of tin and tungsten minerals are found should receive attention. The silver-cobalt-nickel deposits of Cobalt resemble very closely those of Joachimsthal, but the occurrence of pitchblende has not been reported.[1]

[1] Miller, W. G.: The cobalt-nickel arsenides and silver deposits of Temiskaming. Report of the Bureau of Mines (Ontario), vol. 19, part 2, p. 10, 1913.

Pegmatite dykes should be examined. These are particularly abundant in the Pre-Cambrian area of eastern Ontario and western Quebec. These dykes are composed chiefly of quartz and feldspar and are usually very coarse grained, so much so that large fragments of either of the two minerals can be readily separated from the mass. It is from these dykes that feldspar produced in Ontario and Quebec is obtained. In similar rocks a great number of rare minerals and of gem stones are found.

Powdery and crystalline minerals of a bright yellow to emerald green colour, and heavy minerals of a dull or greasy lustre should be tested. In the search for radium-bearing minerals the prospector should keep in mind the possibility of discovering others of economic importance. Any mineral of striking appearance, especially one that is considerably heavier than a piece of quartz or feldspar of equal size, is worthy of examination.

Statistics

The statistics here given may be of interest. It will be seen that at no time has any great quantity of uranium ore been produced.

The United States is said to possess in the carnotite deposits of Colorado and Utah the largest known supply of radium-bearing minerals in the world.[1] The total production of pitchblende ore from the German and Belcher mines, Colorado, from the autumn of 1911 to January 1, 1913, was:—

240 pounds of ore containing more than 70 per cent U_3O_8.
220 " " " " " 20 per cent U_3O_8.
5 tons of ore containing more than 2·6 per cent U_3O_8.
1 ton " " " " 2 per cent U_3O_8.

[1]Moore and Kithil: Bureau of Mines, Wash., Bulletin 70, p. 45.

Messrs. Moore and Kithil also state that in the United States there was a total production of 28·8 tons of uranium oxide during the year 1912, not including 1·4 tons of uranium oxide that was shipped but held up in transit owing to the uranium oxide content being so low that it could not be marketed.

Hess[1] gives the following statistics regarding the production of uranium ores.

Year	Bohemia pitchblende. Short tons.	Cornwall, uranium ore. Short tons.
1897	48·9	
1898	56·2	
1899	54·5	
1900	57·4	
1901	53·3	88
1902	51·2	58
1903	49·7	7
1904	19·0	0
1905	18·0	115
1906	17·8	12
1907	12·4	80
1908	10·1	80
1909	8·9	7
1910	7·2	85
1911	6·4	75
1912		47

Regarding prices paid for carnotite, Moore and Kithil[2] give the following:—

"The prices paid for ore vary within narrow limits. One agent offers for 2 per cent U_3O_8 ore, $1.30 per pound of

[1]U. S. Geol. Survey, Mineral Resources, Part 1, Metals, 1912, pp. 1023 and 1026.

[2]Bureau of Mines, Wash., Bulletin 70, p. 34.

uranium oxide; for 2½ per cent ore, \$1.40; and for 3 per cent ore, \$1.50. For the V_2O_5 content he pays \$0.30 per pound. These prices are f.o.b. New York. An operator who has received offers from several agents states that the prices quoted vary from \$1.25 to \$1.40 per pound of uranium oxide for 2 per cent ore, and \$0.35 per pound of vanadium oxide for ore containing more than 3 per cent of this oxide. Some operators sell their output entirely upon the basis of its uranium content and get nothing for the vanadium. Such a basis usually prevails where the ore is fairly high in uranium and low in vanadium. Where the ore is high in vanadium it is sold for both its vanadium and uranium content according to the prices stated above. When the vanadium is not paid for, the average price given for ore containing 2 per cent U_3O_8 is \$2 per pound, and for 3 per cent ore \$2.25 per pound. Little more is offered for ore containing 3 to 5 per cent U_3O_8, but for ore containing more than 5 per cent the rate is higher. The high-grade material from 'bug holes,' carrying 12 to 20 per cent U_3O_8 or more, brings about \$3.00 per pound of the oxide. These prices are all f.o.b. New York or Hamburg."

Mlle. Gleditsch[1] as a result of investigations that she carried on in the laboratory of Madame Curie, has arrived at the following conclusions regarding the ratio of radium to uranium in certain minerals.

Mineral	Locality	Radium per 100 parts mineral	Uranium per 100 parts mineral	Ratio Ra: U.
Carnotite	Colorado	$0{\cdot}375 \times 10^{-5}$	16·00	$2{\cdot}34 \times 10^{-7}$
Pitchblende	Joachimsthal	$1{\cdot}48 \times 10^{-5}$	46·10	$3{\cdot}21 \times 10^{-7}$
Pitchblende	Cornwall	$1{\cdot}07 \times 10^{-5}$	28·70	$3{\cdot}74 \times 10^{-7}$
Torbernite	Portugal	$1{\cdot}30 \times 10^{-5}$	39·03	$3{\cdot}33 \times 10^{-7}$

[1] Le Radium, vol. 8, 1911, pp. 256-273.

This means that carnotite carries 0·00000375 gram of radium per 100 grams of mineral carrying 16 per cent of uranium, or that for every gram of uranium in the mineral there is 0·000000234 gram of radium. If Mlle. Gleditsch's figures are correct for Colorado carnotite in general, then one ton of uranium in these ores would carry 213 milligrams (3·28 grains) of radium or 396 milligrams (6·1 grains) of radium bromide ($RaBr_2 \, 2H_2O$), the form in which it is usually sold.[1] The proportion of radium in the pitchblende tested from Joachimsthal and Cornwall is somewhat higher.

Owing to the infinitesimal amount of radium present in the ore the cost of recovery is extremely high. "Many experiments have been made in the United States with the object of separating radium from carnotite, but most experimenters have found that the cost of extraction of the minute quantities contained in the ore, including the cost of mining, transportation, chemical and technical knowledge, was so great that even with the enormous prices quoted for radium the process did not pay."

[1] Hess: U. S. Geol. Survey, Mineral Resources, Part 1, Metals, 1912, p. 1008.

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